**Architectures**

I. Mars Exploration

II. Science Emphasis for the Moon and Mars

III. Moon to Stay and Mars Exploration

IV. Space Resource Utilization

An architecture is both a set of objectives ordered to achieve an overall capability and the sequential series of missions (including specific technical activities) to implement those objectives. Subsequent sections of this chapter discuss the considerations and constraints affecting all architectures, the common elements across the architectures and the four architectures.

## Commonality of Architectures

Although the architectures presented here differ, there are common aspects that relate to mission sizing, launch opportunities, duration and surface activities. The dates provided are estimates based upon the optimum launch opportunities for Mars. The dates are notional and depend upon available resources and technological development.[1] The target year for the first landing of humans on Mars, 2014, is common to all architectures, except Architecture IV. Architecture IV has a first landing in 2016. The year 2014 is chosen conservatively to allow for accomplishing the necessary system demonstrations and preparations on the Moon prior to attempting the challenging Mars mission. This also coincides with the opening of a 15-year synodic period of optimum low energy Earth-to-Mars missions. Missions to Mars are possible on 26-month intervals. Recognizing there can be program delays, the President's goal of a landing by 2019 is still possible with alternate Mars opportunities in 2016 and 2018. The synodic window starts to narrow in 2020. Although some flexibility is possible with the dates for lunar activities, they are selected in order to accomplish activities specified by individual architectures, and to properly certify equipment and procedures for the Mars mission in preparation for the initial launch date.

All Mars architectures are designed for a 30 to 100 day stay for the first mission and an approximate 600 day stay for subsequent missions. This leads to total mission durations of approximately 500 and 1,000 days respectively. It is assumed that after the first human Mars mission, coupled with the experience gained on the Moon, confidence in systems and human capabilities will allow for longer duration missions. A crew of six was selected for both the Moon and Mars missions to achieve maximum commonality for equipment, crew tasks and procedures. For the first two piloted missions to the Moon, one crew member remains in orbit to perform inflight experiments and to monitor the orbiting vehicle while the other five descend to the surface. All six go to the lunar surface after sufficient confidence is gained that the orbiting vehicle remains in an acceptable status while unattended. At Mars, all crew members descend to the surface for every mission, as the reliability of the unattended vehicle has been verified around the Moon. This reduces the hazards associated with space radiation and prolonged time periods in zero gravity.

Architectural activities are described in terms of Initial Operational Capability and Next Operational Capability on both the Moon and Mars. These concepts are used for three reasons: to provide a point at which accomplishments to date can be meaningfully evaluated; to provide decision points at which a given program can be continued, modified, or stopped; and to let each mission contribute to the capability required to meet the next operating level in the sequence. After the lunar Initial Operational Capability in all architectures, a decision can be made to conduct the preparation-for-Mars lunar mission and then proceed directly to the Mars mission.

## Diversity of Architectures

Architectures described offer diverse approaches, emphases and program scope and scale for the Space Exploration Initiative. From a thematic aspect, different architectures vary as to the degree of human presence in space, the level to which exploration and science are pursued, the extent to which space resources are developed, and the relative emphasis between lunar and Martian activity. Regardless of the primary emphasis of a given architecture, the other two emphases are always included, as shown below.

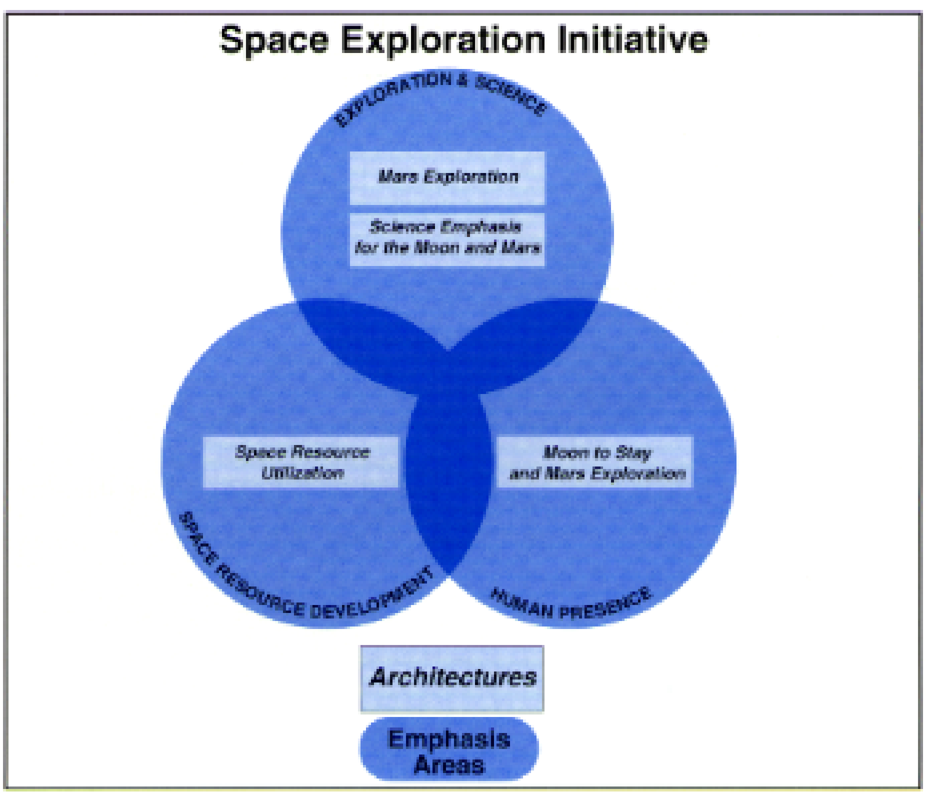
Time in lunar orbit to prepare for Martian missions varies from a total of 120 to 460 days, depending on the architecture. Although the 120 day stay time does not exactly duplicate the Mars transit time, it is felt that this time could be extrapolated with a high degree of confidence.

The use of the Mars transfer vehicle, in conjunction with a surface emplacement on the Moon, would allow mission-critical studies into the physiological effects of the factional Earth-normal gravitation exposures following extended zero gravity stays. This objective can be accomplished with a high degree of operational fidelity on the Moon, and the ready access to zero gravity or fractional gravity would permit a rapid accumulation of data. Simulations of Mars gravity on the lunar surface, using a weighted spacesuit, would allow refinement of gravity-response curves.

The Mars transfer vehicle would have a number of other key missions in addition to life science activities, including simulations of Mars missions, complete with excursions to the Martian (lunar) surface and return, the use of an orbital platform for lunar or astronomical observations, and as a test bed for other essential Mars transfer vehicle subsystem development.

Considering the three different areas of emphasis and the variations in lunar and Mars activity, four architectures have been defined. The *Mars Exploration* architecture places an emphasis on Mars rather than on the Moon. Only activities absolutely necessary to prepare for the Mars mission are planned for the Moon. However, this still allows for meaningful lunar scientific return as a byproduct. The second architecture, ***Science Emphasis for the Moon and Mars,*** explores both the Moon and Mars and uses the Moon as an observing platform with an integrated strategy of robotic and human missions. The third architecture, ***The Moon to Stay and Mars Exploration,*** emphasizes human presence on the Moon, with smaller crews engaged in exploration and science at Mars. This architecture is designed to establish a permanent presence for humanity on the Moon so that significant exploration and observation can be accomplished. The fourth architecture, ***Space Resource Utilization,*** emphasizes the development of lunar resources to provide energy for Earth and the production of propellants to be used for lunar launch and surface operations, and potentially for Mars.

[1] Norman R. Augustine, Chairman of the Advisory Committee on the Future of the U.S. Space Program, addressed the Synthesis Group. When asked what was meant by "go-as-you-pay" in the report, he answered that "The Space Exploration Initiative should be programmed to proceed at a schedule consistent with available funding and the establishment of a solid technology underpinning. When there are problems in the program, as there will always be, the schedule should be slipped rather than taking money from other smaller programs such as the research program."



The Space Exploration Initiative architectures are based on the priorities of safety, cost, performance and schedule. This differs from the Apollo program priorities of safety, schedule, performance and cost. These priorities and the lessons learned from previous experience establish a philosophical baseline of specific concepts and ideas that are common to all Initiative architectures.

## Crew Safety

Crew safety is the prime consideration for human spaceflight operations. Missions which include both long duration flight and planetary surface stays require system designs and operations concepts that maintain crew health and safety. Due to the communications delay on a mission to Mars, the crew will need to operate independently for critical phases. Mars missions require redundancy in system design and abort options. Propulsion systems, landers and habitat modules require reliable and redundant design to reduce vulnerability to failure.

The following principles were identified to ensure crew safety:

- Multiple levels of parallel redundancy with high reliability and low maintenance requirements
- Capability for both the crew and built-in systems to monitor and control all critical functions during normal and contingency operations without support from Earth
- Capability for the crew to manually control and override critical systems
- System designs which allow crew maintenance or repair
- System and consumable margins which reflect resupply rates

The Synthesis Group established mission abort principles for the architectures. Options were considered for each phase of the mission. While it is understood that establishing generic guidelines for abort strategy is difficult at best, basic principles are required to establish criteria for planning. The basis for all abort options is to reduce vulnerability to failure by system reliability and redundancy, and to provide flexibility to the mission commander to execute an abort mode if necessary (Table 1).

Essential functions must be tolerant to multiple failures and must be restorable. System design requires that the first failure results in no operational degradation; the second leaves the system operational, but possibly in a degraded mode; and the third leaves it in a safe and restorable configuration. Thus, the third failure is not catastrophic and the time to restore the function, at least to a degraded operational mode, is less than the time leading to an irreversible catastrophic condition.

*Table 1*

| Phase | Abort Principles |
|---|---|
| Enroute To Moon | Reduce Vulnerability to Failure by System Reliability and Redundancy<br>Provide Trans-Earth Injection Fuel or Use Free Return Trajectory |
| Enroute To Mars | Reduce Vulnerability to Failure by System Reliability and Redundancy<br>Provide Trans-Earth Injection Fuel |
| Moon and Mars Orbit | Reduce Vulnerability to Failure by System Reliability and Redundancy |
| Ascent/ Descent To/From Surface | Reduce Vulnerability to Failure by System Reliability and Redundancy<br>Provide Both Abort to Surface/Orbit and Options to the Commander |
| Planet Surface | Reduce Vulnerability to Failure by System Reliability and Redundancy |

## Mission Opportunities

In order to understand the complexities of interplanetary spaceflight, certain terms must be explained. These terms are:

*Engine Specific Impulse:* Expressed in seconds, the engine thrust in pounds divided by the propellant flow rate in pounds per second.

*Thrust-to-Weight Ratio:* The ratio of the engine thrust to the engine weight.

*Delta-V:* Transportation systems to the Moon and Mars require a series of propulsive maneuvers which result in a velocity change for the spacecraft. This velocity change is called delta-V, expressed in units of velocity (km/s) and related to the amount of energy, and thus fuel, that a spacecraft requires for a mission.

*Initial Mass in Low Earth Orbit:* The total mass, fuel, transfer vehicle, lander, etc. placed in low Earth orbit to accomplish a space mission.

When Apollo crews went to the Moon in the late 1960s and early 1970s, they accomplished the mission in the following phases:

- Earth to orbit
- Earth orbit operations
- Trans-lunar operations
- Lunar orbit operations
- Descent to surface
- Surface operations
- Ascent from surface
- Lunar orbit operations
- Trans-Earth operations
- Earth entry

The total delta-V for the trip was 5.6 km/s from low Earth orbit to lunar orbit and back. It took three days to travel the 400,000 km from the Earth to the Moon.

The Earth orbits the Sun once every 365.25 days in a nearly circular orbit with a radius of 149.5 million kilometers. The mean speed of the Earth relative to the Sun is 30 km/s. Mars, on the other hand, orbits the Sun every 686.79 days (1.88 Earth years) in an elliptical orbit with an eccentricity of 0.1. Although the mean distance from the Sun is 227.8 million kilometers, the eccentricity of the orbit results in a 20% difference in distance from the Sun at the two extremes of the orbit; the Mars orbital speed varies between 22 to 26 km/s. Further complicating matters is the fact that the orbital planes of Earth and Mars are inclined relative to each other at 1.9 degrees, rather than being co-planar.

With the difference in orbital periods, "similar" launch opportunities occur only once every 26 months. A similar launch opportunity is one in which the planets have the same heliocentric angular orientation, or phase angle, relative to one another, as shown in Figure 1. However, the eccentricity in the Martian orbit, combined with the orbital speed differences between Earth and Mars, mean that exact launch cycles repeat only once every 15 years. Even though the same phase angle for a launch opportunity for a given mission occurs every 26 months, the distances between the planets and their relative speeds are different, which lead to different energy requirements and trip times from one opportunity to another.

The phases of the Mars mission are:

- Earth to orbit
- Earth orbit operations
- Trans-Mars operations
- Mars orbit operations
- Descent to surface

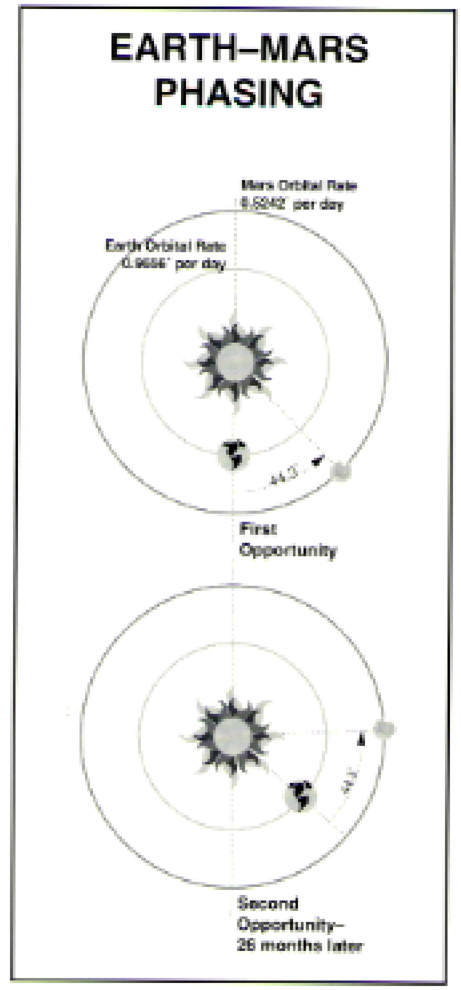



Figure 1

- Surface operations
- Ascent from surface
- Mars orbit operations
- Trans-Earth operations
- Earth entry

The delta-V requirements for the trip from low Earth orbit to Mars orbit and back vary from approximately 8.2 km/s to 24 km/s, depending on the launch opportunity.

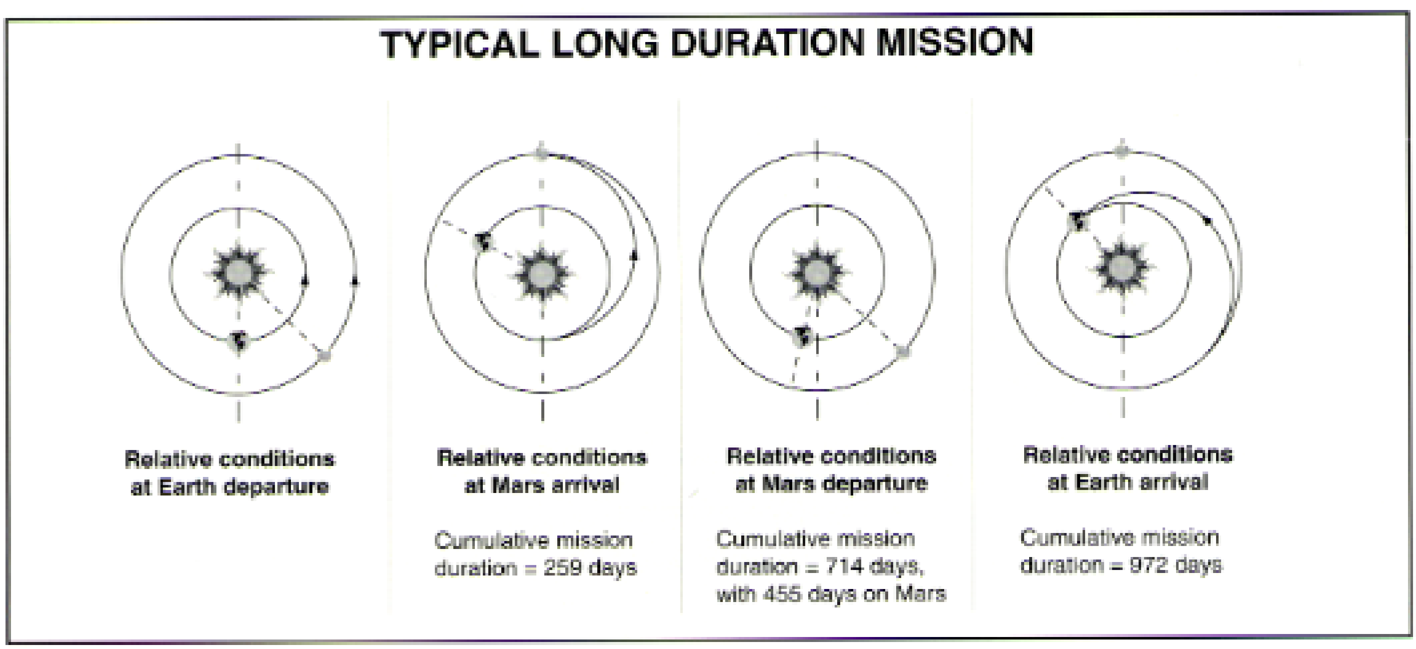
## Mission Duration

Missions to Mars fall into one of two classes: long duration missions (conjunction class) and short duration missions (opposition class). A long duration mission trajectory traverses a heliocentric angle of about 180 degrees during each orbital transfer, with tangential departure and arrival, as shown in Figure 2. The transfer trajectory, known as a Hohmann transfer, is the minimum energy orbital transfer. This mission duration is on the order of 1,000 days, with a typical stay time at Mars of approximately 500 days. The delta-V requirements for long duration minimum energy missions are fairly constant, varying only about 10% over the 15 year cycle.

Short duration missions are on the order of 500 days total trip time, with a 30 to 100 day stay at Mars. One of the transfer legs, either the outbound or inbound, must have a deep space propulsive maneuver. This maneuver can be replaced with a Venus swing-by, which is more efficient from a propulsive energy requirement, but requires that Venus be in a particular phase with both Earth and Mars. The Venus swing-by uses Venus's gravity to modify the trajectory and shorten the trip time and reduce the delta-V. Due to a combination of the eccentricity and the inclination of the Mars orbit, the delta-V requirements for short duration missions can vary with launch date by as much as a factor of two. The best short duration mission opportunities occur in 2003 and 2018. The transfer legs of a typical short duration mission are shown in Figure 3.

There are two major propulsion options for the Mars missions: chemical and nuclear. Both options are compared in Figure 4 for the 2014

*Figure 2*



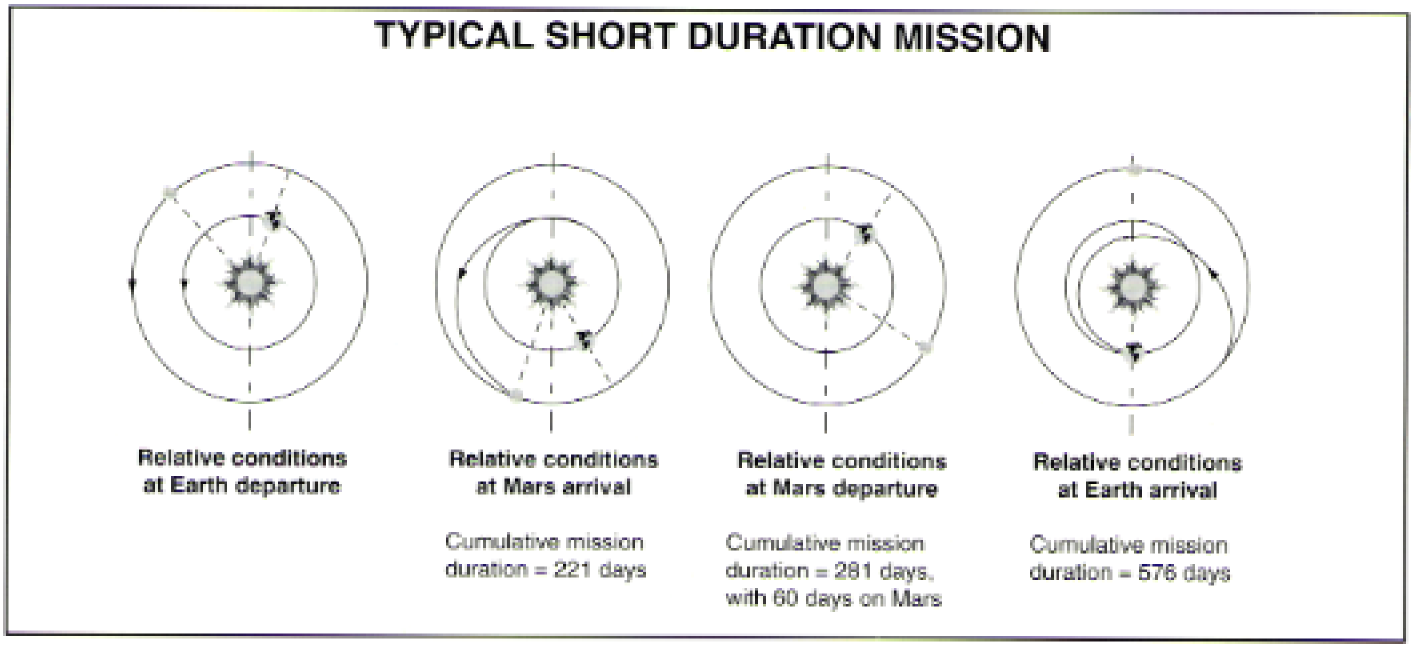
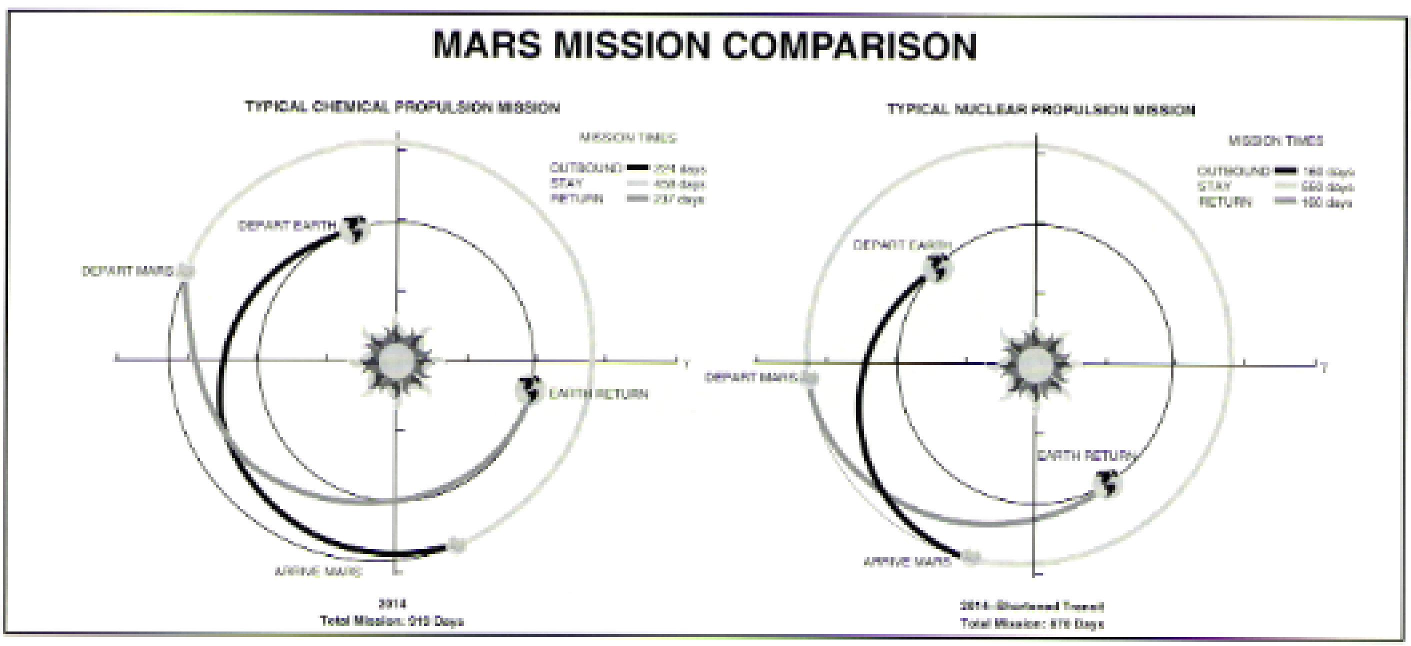



*Figure 3*

opportunity. Chemical systems have the advantage of being a well developed, flight-tested technology. Unfortunately, chemical systems are limited in performance, with large propellant mass requirements in low Earth orbit and major restrictions in launch opportunities. Nuclear systems, on the other hand, promise high performance with significant savings in propellant mass. Although nuclear thermal rocket technology was demonstrated in the 1960s, it has not been flight tested.

Launch costs are heavily dependent on the required initial mass in low Earth orbit. Therefore, cost constraints tend to lead toward mission configurations with lower delta-V requirements, and correspondingly

*Figure 4*



lower propellant masses and longer transit times.

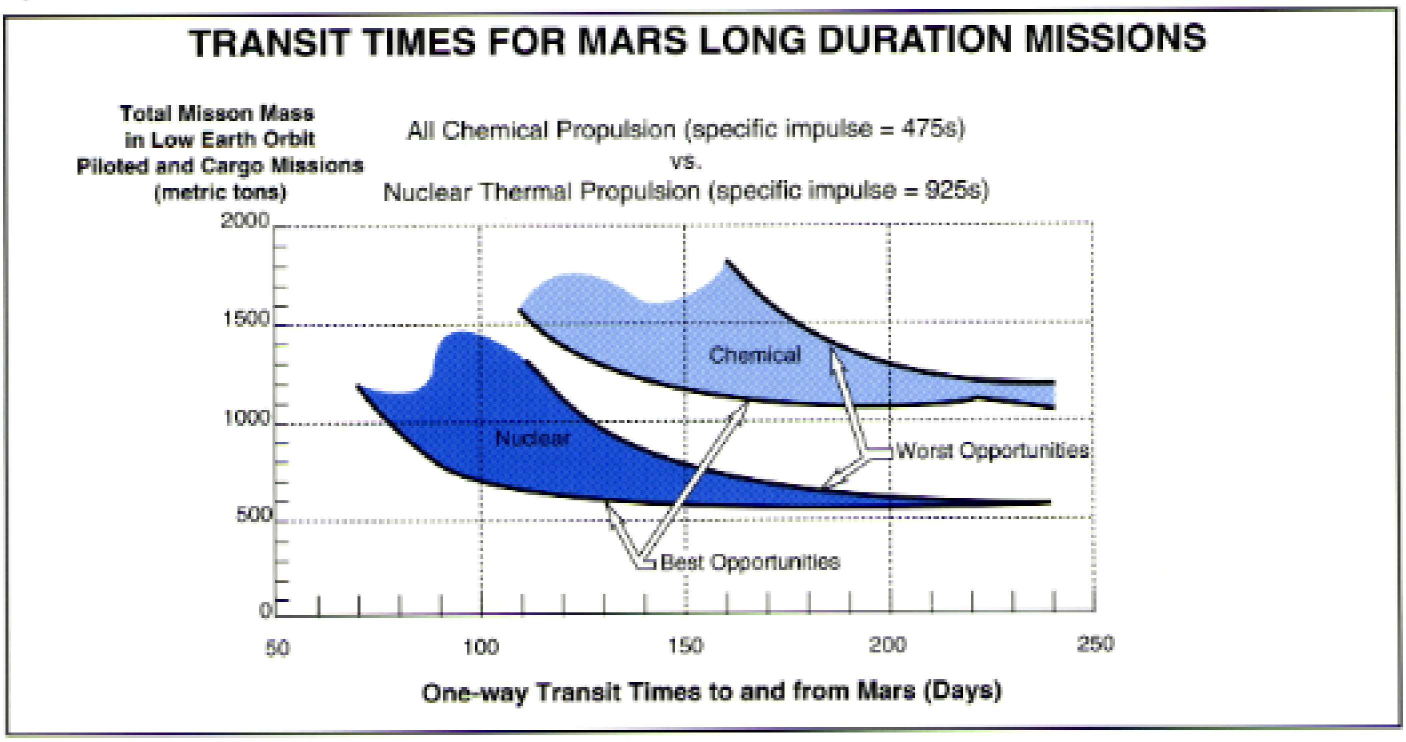
Biomedical and psychological concerns relative to the effects of prolonged zero gravity, space radiation, and confinement during Mars missions are strong incentives to reduce transit times.

Mission architectures represent tradeoffs between these competing concerns. Separate missions are one solution, in which different spacecraft are used for personnel and for cargo. This allows the lighter piloted vehicle to make quicker trips with reasonable delta-V's, while the heavier cargo vehicles travel a longer, lower energy trajectory.

In order to assess potential architectures, several missions were evaluated for launch opportunities from 2008 to 2022. The best and worst opportunities for this time frame are shown in Figures 5 and 6. Chemical (475 seconds specific impulse) and nuclear (925 seconds specific impulse) propulsion sources were considered for both a long and short duration mission. The long duration mission consisted of approximately 400 days of round trip transit time with 600 days on the surface, while the short duration mission consisted of approximately 460 days round trip transit time with 30 days on the surface.

Figure 5 shows that chemical propulsion systems require approximately 1,100 or more metric tons in low Earth orbit for long duration missions at the best opportunity. Approximately 1,300 or more metric tons are required for short duration missions for the best opportunities, as shown in Figure 6. These figures also show that nuclear propulsion systems require approximately 500 or more metric tons for long duration missions and 600 or more metric tons for short duration missions at the best opportunities. In addition, for nuclear propulsion missions, round trip times for long duration missions can be reduced from 400 days to about 320 days with only a modest increase in propellant mass. Short duration missions with a 470 day round trip transit can have either the trip time reduced or the Mars surface stay

*Figure 5*



extended from 30 to 100 days at an increase of 100 to 200 metric tons in the initial mass to low Earth orbit during favorable years.

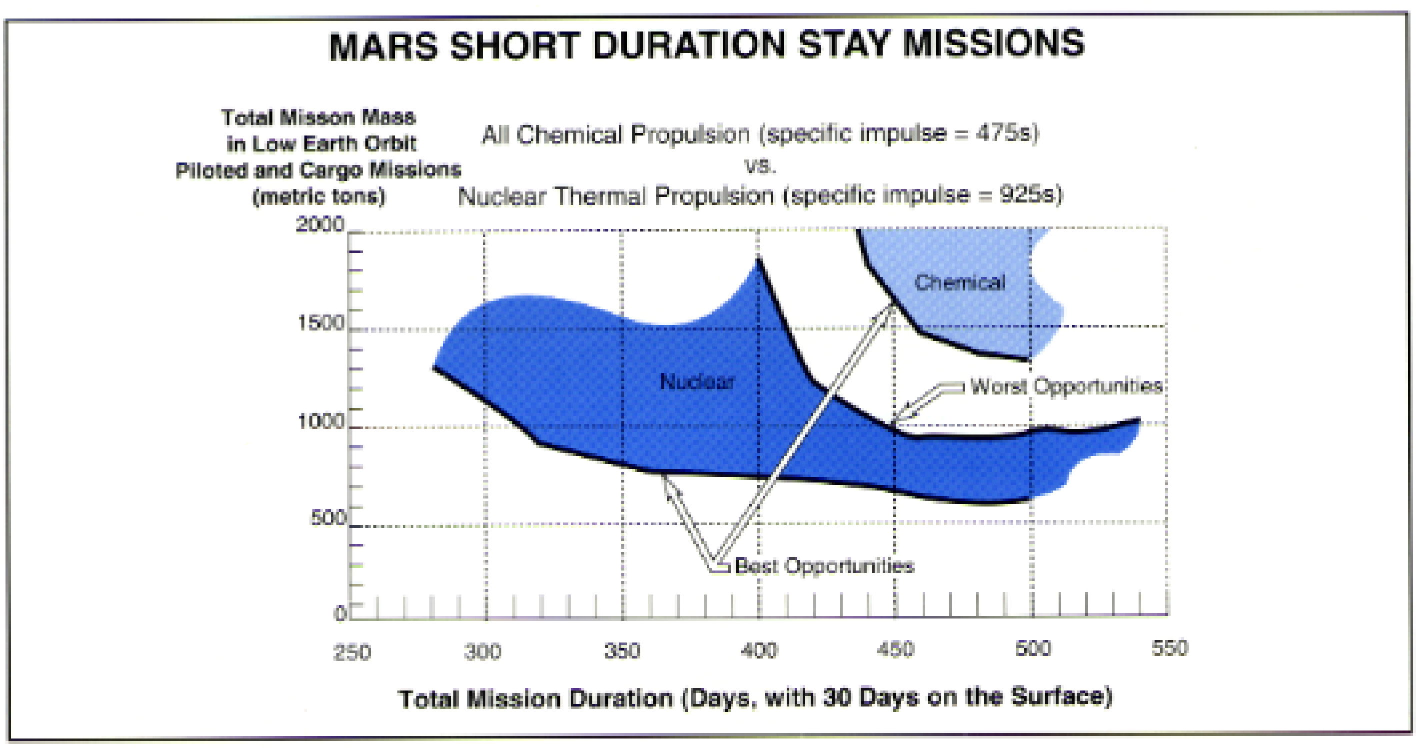
The total number of launches per mission would be limited by the need to minimize on-orbit assembly and at the same time meet available launch windows. For example, using a heavy lift launch vehicle with a 250 metric ton payload capacity, and operating with a maximum system linkup capability of three launch modules, the initial mass to low Earth orbit needed for a total trip would be limited to a maximum of 750 metric tons. Volume constraints and spacecraft design considerations may apply additional limitations. These types of practical limits were considered in evaluating potential missions.

## Space Radiation

The space radiation environment outside the Earth's magnetosphere is composed of two types of radiation which present a potential health hazard: galactic cosmic and solar flare events.

The galactic cosmic radiation environment is reasonably well known, yet there are uncertainties with respect to biological effects and related risk assessment. The allowable annual radiation exposure for the astronauts' blood forming organs is 50 REM — a dose of radiation called "Radiation Equivalent Man." During the Mars transfer, the unshielded radiation dose rate will range between 24 and 60 REM per year as a function of the solar cycle (galactic cosmic radiation is maximum during solar minimum). The expected galactic cosmic radiation dose received by an unshielded astronaut on a trip to Mars is below the allowable amount based on the annual 50 REM limit adopted for Space Shuttle astronauts. Shielding to reduce the highly penetrating galactic cosmic radiation is impractical, due to the enormous weight penalty that must be paid to shield the entire spacecraft. Selective materials integrated into the spacecraft design, however, can reduce the

Figure 6



radiation effects. Reducing the trip time is the best method to limit the galactic cosmic radiation exposure to the crew. Once on Mars, the planet and atmosphere provide adequate protection.

Solar flare events may be incapacitating or lethal for an unshielded astronaut; however, the short duration and the energy spectrum of solar flare events (lower than the energy spectrum of galactic cosmic rays) make radiation storm shelters an effective countermeasure. The mass penalty for shielding can be reduced by using water for passive shielding. The excess water required will also enhance safety by providing a backup to water loop closure systems. A radiation storm shelter with 16 $gm/cm^2$ of water is estimated to provide adequate shielding against anomalously large solar flare events. Solar monitoring satellites and observations from Earth will enable long range predictions of solar flare activity for mission and extravehicular activity planning purposes. In addition, onboard radiation monitors will provide real time warning to alert the crew to seek the shelter during an event.

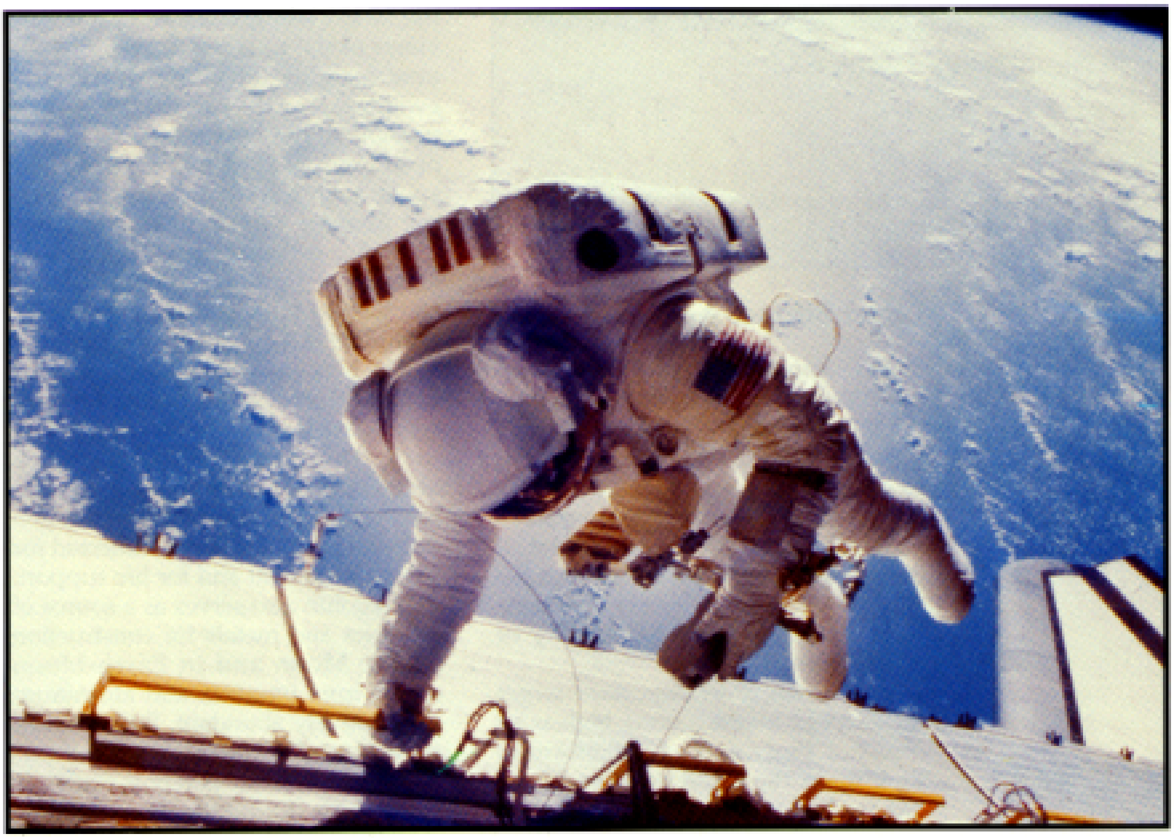
Biological experience gained from operations in the lunar environment, along with passive radiation shielding and reduced trip times, should provide adequate protection to the crew for the Mars missions.

## Zero Gravity

The issue of mission duration is central to the discussion of architectures. Within the context of the proposed exploration missions, there are several distinct gravitational environments. Extended stays on the lunar surface will result in exposure to one-sixth the Earth's gravity. Mars missions will entail exposure to zero gravity during the outbound leg, three-eighths the Earth's gravity during surface stays of 30 to 600 days, and zero gravity during the return trip. Human exposure to zero gravity results in a deconditioning process, which is related to the time spent in the reduced gravitational field.

The existing knowledge base for deconditioning from long term zero gravity exposure consists of Skylab data, up to 84 days duration; and Soviet Mir space station data, with up to 366 days duration. These experiences, to be confirmed with additional research, indicate that with appropriate countermeasures, a crew can be maintained in satisfactory condition throughout long duration flights; therefore, artificial gravity is not incorporated in the four architectures. It is expected that while crews are on the Martian surface, the three-eighths Earth's gravity will help maintain their physiological health.

It is necessary to fully understand deconditioning effects in order to ensure that Mars missions are conducted in a safe manner. The approach recommended involves crews using a Mars transfer vehicle crew compartment in lunar orbit and then descending to the lunar surface to provide simulation for Mars missions. This would allow rapid accumulation of adaptation data. This simulation capability will be used to develop and test effective countermeasures. Mars missions will be designed to minimize, to the degree possible, the time spent in zero gravity.



*Astronaut Working in Zero Gravity*

The journey to the Moon and Mars will consist of many different activities, both on planetary surfaces and in orbital and interplanetary flight. The common architectural strategies are shown below.

**Common Architectural Strategies**

- **Involve the public in the adventure of exploration**
- **Provide for significant science return**
- **Emphasize educational return**
- **Encourage and facilitate benefits for commercial applications and for the industrial sector**

## Lunar Surface Activities

Surface activities at the Moon encompass the three primary components of the Initiative: science and exploration, human presence, and space resources. In each activity, specific tasks, equipment and strategies are employed to accomplish mission objectives. Not all activities are undertaken at once; the relative extent of each activity is partly responsible for the diversity of architectures.

The Moon is an important target for scientific investigations, both as an object of study and as a platform to look upon the universe. The Moon has undergone a complex and protracted geologic evolution, including the formation of a crust and mantle, impact bombardment, flooding of the surface by volcanic lavas and deformation of the crust by fracturing. The lunar soil (regolith) contains a four billion year history of the output of the Sun. The craters of the Moon record the variations in the impact flux in the Earth-Moon system. The complexity and richness of the lunar geologic record can be deciphered to give us an unprecedented view of the origin and evolution of the Earth-Moon system.

With its low gravity, vacuum and long nights, the Moon is an excellent site from which to observe the universe. It is a stable platform where delicate astronomical instruments can be emplaced and operated to give detailed views of our own and neighboring star systems. Moreover, the observation instruments can scan the entire electromagnetic spectrum from the lunar surface. Observatories on the Moon will give us incomparable views of the universe and Earth and new insights into their origin and evolution. For the first time, it will be possible to resolve the apparent disks of individual stars and observe star spots; such resolution may also permit imaging of other planetary systems. For extra-solar planets, surface features of Jupiter-sized planets can be mapped while full disk spectra of Earth-like planets can be obtained.

The Moon is a source of both materials and energy for an emerging space-based economy in the 21st century. The lunar regolith contains absorbed solar light gases (e.g., hydrogen) and indigenous oxygen that can be extracted and collected for use as propellant and for life support. The regolith also serves as a source of ceramics and metals for construction on the Moon and in Earth-Moon space; iron, titanium and aluminum are relatively abundant. Bulk soil can serve as radiation shielding for surface habitats. Solar power is constantly available during the lunar daytime (14 Earth days). Finally, the rare isotope Helium-3 is present in the lunar soil; this material may ultimately power terrestrial fusion reactors in the next century, providing clean and safe electrical energy.

The Moon is a place for humanity to live and work in the 21st century. It is a small planet with natural, reduced (1/6) gravity; in total area, the Moon is roughly equivalent to the continent of Africa. The materials and energy needed for human habitation on the Moon are readily extractable from surface materials. The Moon is only three days from the Earth and the near side has a constant and psychologically reassuring view of our home planet. It is a natural "space station" orbiting planet Earth.

Lunar missions and preparations are essential prior to accomplishing piloted missions to Mars. Without flights to the Moon, more than 40 years will have passed since the latest piloted mission beyond low Earth orbit. The Moon is relatively accessible and return to Earth is readily accomplished (as compared to a Mars mission) if emergencies occur. The topography and environment of the Moon are used to simulate Martian conditions. As a part of this approach, it is important to test and operate the actual equipment and systems to be used for the Mars mission. The only way to prove that equipment and systems are truly reliable is to test their functions and operate them over long periods of time in realistic environments.

The Moon provides a testing environment of human performance to ensure the safety of the crew. The issue of human performance after long exposure to zero gravity, and the effectiveness of countermeasures to long term exposure to zero gravity, must be well understood before sending crews to Mars. The degree of autonomy required in systems and equipment is better assessed after understanding crew adaptability to a reduced gravity environment. Simulations of human stay time are required between time spent on the lunar surface and in space-based facilities. Human adaptation at the Moon is measured after spending sufficient time in reduced gravity. Crew members adapt in facilities on the Moon, performing tasks similar to those required at Mars. These crew members also experience the psychological effects and isolation that are experienced by crews traveling to and from Mars. Operational concepts are developed to make best use of the systems and crew on the planetary surfaces. This applies to robotic and telerobotic systems, as well as human activities.

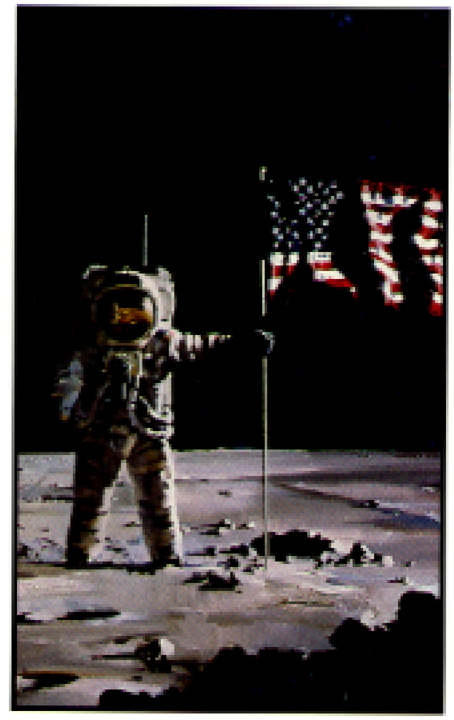
## Martian Surface Activities

The exploration of Mars involves several scientific disciplines that deal with the study of Martian origin, geological processes, and evolution. All architectures envision a robust Mars exploration program that consists of complementary robotic and human mission elements. The exploration program is designed to give first-order answers to some of the most fundamental questions of planetary science.

Scientists are interested in the geological, climatological and biological processes that now act or have acted in the evolution of Mars. Mars has a complex history, involving impacted projectiles from space, internally generated magmas that both intrude the crust and spill out on it (volcanism), tectonic forces that deform and fracture the planet's surface, and erosion and deposition by wind, water and ice. Geological processes that have shaped all the terrestrial planets have acted to one degree or another on Mars.

Although Mars is currently cold and has a very thin atmosphere, it is believed that conditions were much more Earth-like several billion years ago. At that time, Mars apparently had a thicker, warmer atmosphere, running water, and a more moderate climate. Because these conditions could have supported life, the search for traces of former Martian life (fossils) is an important objective in the exploration of Mars.

For some reason, the benign Martian climate changed; the atmosphere thinned, temperatures cooled, and the existing surface water either sublimated into the atmosphere and was subsequently lost to space, or became frozen as ground ice. Why this dramatic change occurred is one of the major puzzles of Martian history. Moreover, it may be a cautionary



*American Exploration*

tale for Earth-dwellers, since the dynamics of global climate change are as poorly understood as they are life threatening. With the concerns over Earth's global warming and the long term effects of pollution on the environment, the history of Mars holds valuable insights that will assist in understanding and improving the Earth's evolving environment. Studying Mars also helps in understanding planetary processes and formation and in understanding the history of the Solar System. The exploration of this planet millions of miles from the Earth complements the efforts of Missions to Planet Earth and could hold a key to understanding our own planet.

**Surface Science Activities (100 days)**
The arrival of humans on the surface of Mars opens new vistas of scientific accomplishment. Field studies become possible when human powers of observation and thought are present, both through the actual presence of humans and by extension through telepresence, the projection of some human powers of discernment and cognition through a machine.

Each mission carries a pressurized rover, giving the crews access to areas within a 50 km radius of the landing site for the first flight, increasing to a 100 km radius in subsequent missions. Because they will have been preceded by a robotic surface rover, the crew's first task is to thoroughly characterize the landing site environment within a radius of 2 km.

Detailed field study of the geology of this area is an ongoing task of the crew members remaining behind while others conduct rover traverses. Experiments are performed on a small scale to test the feasibility of producing fuel from local resources and to demonstrate the capability to grow food in the habitat.

Traverses in the pressurized rover are to sites identified from orbital imagery and the prior surface rover reconnaissance. A crew of two or three travels to examine key geological sites, collect carefully controlled samples, deploy instrument packages and decipher and understand the complex geology of the region adjacent to the landing site. Although general routes are planned and major field sites identified in advance, the unique opportunity of human travel over the Martian surface permits traverse routes and plans to be modified in real time. This capability is the cornerstone of conducting true field exploration, and the maximum possible latitude for operational changes is granted to the crews during the Mars visit. In this way, significant discoveries are most likely to be made and, as important, followed up with additional field work.

As an example, a landing site might be selected adjacent to certain smooth deposits contained within the floor of the Martian canyons; studies have suggested that these deposits represent ancient lake sediments. A site reconnaissance orbiter documents the geologic relations and context of these deposits in some detail and a pre-deployed surface rover obtains data on their surface composition and physical properties, including a search for outcrops and other exposures.

It is left to the crew to examine these deposits and perform geologic field work. This consists of systematically examining, measuring and sampling exposed lake deposits, mapping their extent and continuity, and searching the rock exposures for possible fossil remains. The field work proceeds on both a contingency and an iterative basis. In the first case, the crew's specific field tasks are actively directed by significant findings in the field; these decisions are made by the field crew in real time. In the second case, the crew has the ability to revisit, re-examine and re-sample previously explored field sites, both to supplement new knowledge and to place data into new contexts derived from the evolving conceptual framework. Such work requires insight and geological experience and it constitutes a major contribution by humans to planetary exploration.

**Surface Science Activities (600 days)**
Additional science opportunities are presented by a long surface stay capability. Although the general character of field exploration on a long-stay mission is similar to that conducted during a short stay, more thorough field science of the selected site is accomplished. Return in planetary science is directly proportional to access, capability and time. A significant increase in the amount of time available greatly increases the science return of the mission. Time is available to completely characterize the area surrounding the landing site within the traverse radius of the pressurized rover. An important aspect of extended time on the surface is the ability to revisit sites. Such activity is very common in terrestrial geology and permits the field testing of hypotheses that characterize advanced geologic study.

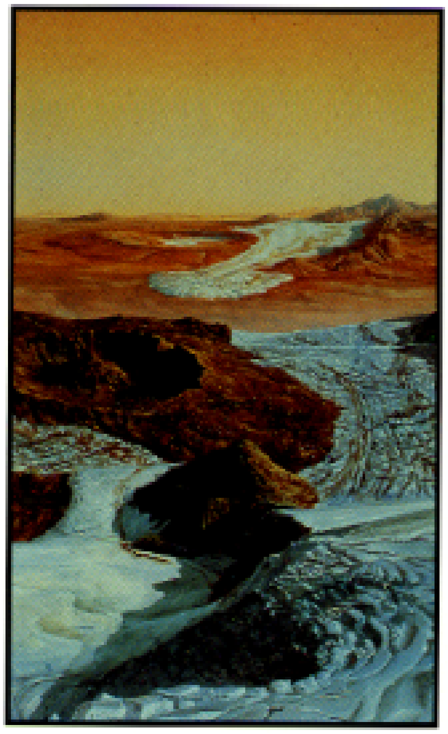
In order to take scientific advantage of extended surface stays, it is necessary to be able to do some first-order analyses of collected Martian materials in the habitat. This small-scale sample analysis laboratory is able to make bulk chemical analyses, rock examination under microscope and compositional analyses of volatiles, including gas and ice. These laboratory functions enable site revisits to have maximum effect, as field geology requires laboratory work interspersed with field collection. Cryptic or subtle properties of the samples hold significant clues to geological evolution, especially in the fields of ancient environment reconstruction and the search for fossil life.

Environmental and meteorological measurements assume increased importance during long stays, as the increased surface time takes the crew through an entire Martian year. Seasonal variations are studied from the surface in great detail; such knowledge is also important in order to protect the crew from possible detrimental environmental effects (e.g., dust storms).

Difficult scientific problems, such as the search for fossil life or understanding ancient climates, require large amounts of time to gather data, understand field relations and reconstruct processes and history. Such problems are particularly amenable to study during long duration missions. While positive results from such an investigation cannot be assured, the chances for definitive answers are much more likely to be derived from extended surface activities than from short stays.

Science investigations on later missions will likely be configured to take advantage of the knowledge derived from the initial visits and will carry additional equipment or capability designed to increase the information return of surface exploration. It is unlikely that the general problems of climate change and the origin of life will be resolved during the first visits. These questions are deemed of great significance and will probably receive attention during any long range exploration plan. To fully address all these questions, many sites would have to be visited, sites that span the range of geological age and diversity evident on the planet's surface. Such access is achieved directly from Martian orbit, or from long range surface travel. The baselined method of surface travel offers the maximum flexibility to the crew to modify exploration plans in real time to accommodate discoveries likely to be made as the surface exploration progresses.

It is possible to greatly increase the science return from Mars exploration through the use of telepresence robots. Such robots permit human presence at many varied and separate sites without the logistic difficulties of physically transporting cumbersome life-support systems. In this operational concept, multiple robots are deployed at widely separated locations



*Martian Surface*

on Mars. These robots are controlled by human operators from a central site either on Mars, near the landing site, or from Martian orbit. Extensive field work is conducted, instruments are deployed and samples are collected by these machines under human control. Samples and data are collected at centralized locations for transport to the Mars habitat for first-order analysis and ultimately, to the Earth-return spacecraft.

## Orbital Activities

If the crew were unable to land and were forced to remain in Martian orbit, a variety of scientific activities would be possible. Orbital science roles for humans fall into three broad categories: operators of instrument platforms, scientific observers in orbit, and participants in surface exploration by means of robotic telepresence.

Orbital instruments are an integral part of the global reconnaissance of any planetary body. Global observations from orbit are largely accomplished by robotic precursor missions. An instrument platform could be built into an orbital vehicle and operated in Mars orbit under direct human supervision, but it has not been baselined. This operation involves instrument cycling, repair and manual contingency operation. The value of humans as instrument operators was demonstrated during Apollo lunar orbital operations, again during the Skylab program and on numerous shuttle flights.

Direct visual observations from orbit allow the crew to examine terrain selectively, identify important or critical elements and decipher or unravel complex geological or meteorological phenomena in near real time. The resolution of direct observation is partly altitude-dependent and is augmented by optical devices (e.g., telescopes). The key factor is the human ability to synthesize disparate data to obtain new geological insight. As an example of how this might happen, the famous orange soil discovered on the Moon by Apollo 17 was little more than a geological oddity until the geologist astronaut recognized regional deposits of orange soil from orbit. Our understanding of the significance of both the samples and its regional extent increased greatly through this direct observation from orbit; we now know that orange soil represents a major phase of volatile-rich lunar volcanism in this region around three billion years ago. Thus, significant clues to planetary geologic evolution may be uncovered through the use of human observations from orbit. Depending upon orbital parameters it might also be possible to conduct scientific observations of the Martian moons, Phobos and Deimos, as well.

The concept of telepresence depends on nearly instantaneous response between the human control operator and the slave robotic system. Orbiting vehicles maintain distances of a few hundred kilometers from the planet's surface, permitting true telepresent operation of robots on Mars by human controllers in orbit. Thus, orbiting crew members become active participants in surface exploration. These telepresent robots act in direct cooperation with the surface crew, as an extra member of the field party or as an independent explorer. In the latter case, the robot makes periodic returns to the surface lander to discharge its cargo of collected samples and stored data not directly transmitted to orbit. This telepresence mode of surface exploration not only greatly extends human reach, by accessing areas either too distant or inaccessible by the surface crews, but also provides a back up capability for surface field work by putting human "presence" on the surface, possibly under conditions in which humans could not effectively operate (e.g., abort conditions, dust storms). This third type of human activity from orbit greatly augments the total scientific capability of the Mars mission.

## Transportation

A heavy lift launch vehicle is the basic capability needed to support any lunar and Martian architecture. The Apollo Saturn V launch vehicle had a lift capability of 140 metric tons to low Earth orbit. This provided a very constrained payload capability to the lunar surface. The Space Exploration Initiative architectures require a more robust system. This has been provided for, in part, by having separate cargo and piloted flights. The mass to low Earth orbit requirements range from a minimum of 150 metric tons up to 250 metric tons per launch. Vice President Quayle asked that we investigate options to accomplish America's exploration goals faster, cheaper, safer and better. This investigation has led to the very clear conclusion that to achieve these goals, the utilization of a heavy lift launch vehicle having a capability to launch 250 metric tons to low Earth orbit is required. The heavy lift launch vehicle significantly affects the ability to implement the architectures defined. All of the lunar and Mars architectures have been baselined with such a vehicle. This allows the architectures to be clearly done faster, cheaper, safer and better than with a less capable launch vehicle. They could be done with a vehicle capable of only 150 metric tons. However, more launches and assembly in Earth orbit would be required, all at odds with the desired goal. A greater lift capacity will require fewer launches to support any architecture, and offers more operational flexibility when launching cargo and piloted missions in the same year.

The need for a new heavy lift launch vehicle has paved the way for an infusion of launch vehicle technology through the joint NASA-Department of Defense National Launch System Program. Many improved production and processing techniques have been identified. These improvements should be incorporated in the contemplated heavy lift launch vehicle. The lessons and the proven technology of the past must also be considered (e.g., the liquid oxygen-kerosene F-1 engines used for Apollo Saturn V, first stage). This combination of propellants and engines offers great potential for the first stage and boosters of a new heavy lift launch vehicle. These engines demonstrated a sea level

*Saturn V Launch of Apollo XVII*

thrust of 1.8 million pounds per engine. Flight engines have a flawless record of performance for 13 flights with 65 engines. The propellants also offer the advantage of having less explosive potential by a factor of six than that of liquid oxygen-liquid hydrogen. There are no environmental issues associated with their $CO_2$ and $H_2O$ by products.[1]

In addition to a heavy lift launch vehicle, all architectures require the capability to dock elements of the lunar and Martian cargo and piloted vehicles in low Earth orbit. Automatic docking of modules, a technique utilized by the Soviets on a regular basis, is required. These operations preclude the need for extensive extravehicular activities in low Earth orbit to assemble lunar or Martian transfer vehicles.

## Technical Strategies

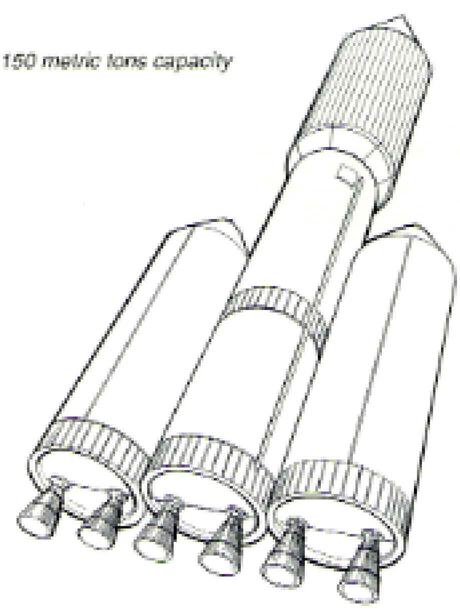
- **Develop a heavy lift launch capability**
- **Limit on-orbit assembly**
- **Develop nuclear technologies**
- **Use the Moon as a test bed in preparation for Mars**
- **Use common systems and operations between the Moon and Mars**
- **Use a complementary mix of human and robotic resources**
- **Emphasize technologies with terrestrial applications**

## Lunar Missions

A typical lunar mission begins with the launch to low Earth orbit of a cargo vehicle containing a habitat, surface power supply, unloader, consumables and experiments. It is launched on a heavy lift launch vehicle with the lunar transfer vehicle injecting the cargo into the trans-lunar phase. Upon lunar approach, the lunar transfer vehicle provides an orbital propulsive capture maneuver to place the cargo and its lander into a lunar orbit. The cargo is then placed at a preselected landing site with the lander. Like the Apollo program, an all-chemical propulsion system is used for lunar missions.

The lunar cargo mission is followed by the piloted mission, containing consumables and experiments, as well as a rover. After launch to low Earth orbit, they are injected into a lunar trajectory by the lunar transfer vehicle, identical to that used for the cargo mission. A propulsive maneuver places the vehicle in lunar

*Heavy Lift Launch Vehicle*



orbit. A piloted lander provides a propulsive descent to the surface.

Upon the completion of their stay on the lunar surface, the crew returns to the lander for launch and rendezvous with the lunar transfer vehicle. A propulsive maneuver is accomplished to place the crew on a course returning to Earth. The crew makes a direct entry into the Earth's atmosphere using an Apollo-type command module.

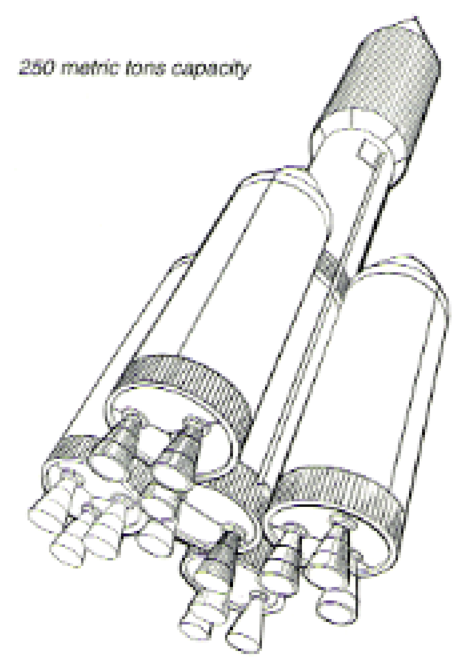
### Mars Missions

The typical Mars mission uses separate cargo and piloted flights. The nuclear thermal rocket is the selected method of propulsion to reduce the transit times and the exposure to zero gravity, space radiation and mass to low Earth orbit. The first mission to Mars is a cargo mission. This mission requires three launches for final assembly. Components of these three launches are then assembled into a Mars mission cargo vehicle using automated, on-orbit rendezvous and docking procedures developed in the lunar phase of the program. The activation of the nuclear engine propels the vehicle out of Earth orbit and on its way to Mars. After reaching the required velocity, the engine shuts off and the vehicle continues its journey. Mid-course propulsive corrections are also required. As the vehicle approaches Mars, the nuclear engine activates for insertion into Mars orbit. The cargo lander is sent to the surface in time to have the emplaced systems activated and checked out before launching the piloted mission.

The piloted vehicle consists of the crew in the Earth-entry vehicle, along with their Mars transfer vehicle, the nuclear engine, inflight experiments and consumables. The crew can be launched in the Space Shuttle, a Space Shuttle follow-on vehicle, or on a heavy lift launch vehicle. After on-orbit rendezvous and docking, the crew activates the nuclear thermal rocket to initiate trans-Mars injection. The piloted vehicle carries contingency trans-Earth injection fuel to permit an abort from Mars orbit.

With Mars orbital capture and rendezvous with the cargo vehicle complete, the crew descends in their piloted lander to the surface of Mars. After completion of their surface stay, they ascend in their lander to orbit, using the same techniques used for the lunar missions to rendezvous and dock with the Mars transfer and Earth-entry vehicles in orbit around Mars. They then undock the vehicle and depart Mars orbit. The crew makes a direct entry into the Earth's atmosphere after injecting the nuclear stage into solar orbit.

*Heavy Lift Launch Vehicle*




[1] NASA, Johnson Space Center, Code XE memorandum dated January 11, 1991, "Preliminary Heavy Lift Launch Vehicle (HLLV) Requirements for the Space Exploration Initiative," Norman H. Chaffee.